Zero-G Corp.
July 2011 Campaign

July 14-22, 2011

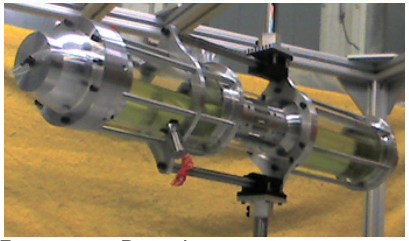
Ellington Field, TX

Manifest

- 003-PS On-Orbit Propellant Storage Stability – Sathya Gangadharan/Embry-Riddle Aeronautical University
- 004-PS Printing the Space Future – Jason Dunn/Made in Space
- 005-P Heat Exchangers – Jungho Kim/University of Maryland
- 006-P Electric Field Effects on Pool Boiling Heat Transfer – Jungho Kim/University of Maryland
- 007-P Radio Frequency Mass Gauge on Parabolic – Greg Zimmerli/ NASA GRC
- 008-P Indexing Media Filtration – Juan Agui/NASA GRC
- 009-P Autonomous Robotic Capture – Brian Roberts/NASA GSFC
- 010-P Validation of Atomization Mechanism and Droplet Transport for a Portable Fire Extinguisher – Thierry Carriere/ADA Technologies
- 011-P Cryocooler – Ben Longmier/Ad Astra

003-P Investigation to Determine Rotational Stability of On-Orbit Propellant Storage and Transfer Systems Undergoing Operational Fuel Transfer Scenarios

STATUS QUO



- *Prototype Development*
  - *Completed*
- *Validation/Ground Testing*
  - *Completed by July 1st, 2011*
- *Parabolic Flight Hardware (TASR)*
  - *Fit Tested/Ready for Flight*
- *sRLV Equipment in Development Stage*

NEW INSIGHTS

Investigation Focus Area:

On-Orbit Propellant Storage and Transfer Technology

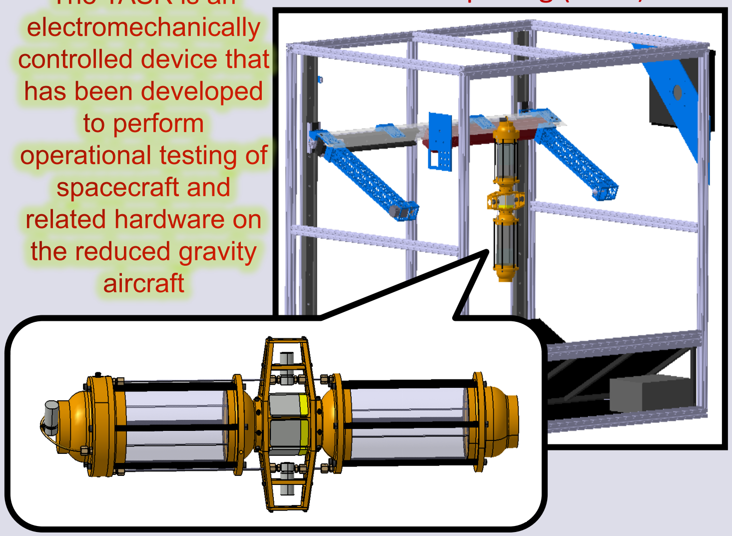
Specific Benefits:

TRL Advancement of On-Orbit Refueling Technology

The advancement of this technology will help enable the aggregation of propellant from multiple launches to enable robust beyond LEO exploration of the Moon, NEO's, Mars and beyond.

The TASR is an electromechanically controlled device that has been developed to perform operational testing of spacecraft and related hardware on the reduced gravity aircraft

Tri-Axis Spin Rig (TASR)



Scaled On-Orbit Propellant Storage and Transfer System

MAIN ACHIEVEMENT: The on-orbit propellant storage and transfer system being tested is derived from the Centaur upper stage of the Atlas launch vehicle. A 1:37 scale mock-up of this system has been developed and is currently being validated through ground testing. Primary test objectives include performing operationally similar propellant transfers between various tanks on the scale system while the system is spun about its minor axis. Secondary objectives include similar transfers between the scale system and an adjacent spacecraft. *Parameters of interest are*: Pressure Gradients between tanks, transfer times, corresponding mass flow rates, and changes in the system's angular acceleration. Liquid propellant slosh as well as capillary effects are expected to develop and are of specific scientific interest.

QUANTITATIVE IMPACT

Quantitative Results:

Results gathered during flight testing will be used to advance the TRL of the proposed technology as well as to validate computational modeling approaches using CFD and mechanical models

Measured/ Parameters:

- Angular Velocity (Spin Rate)
- Angular Acceleration (Changes in system's spin rate)
- Pressure Gradients
- Temperature Changes

END-OF-PHASE GOAL

On-Orbit Refueling of Spacecraft Becomes a Closer Reality

Technology Readiness Level goes from 4 to 6:

- *Testing in relevant environment*
- *Possible Cryogenic testing of operationally similar hardware*
- *Future full scale testing*
- *Prototype development of more advanced systems such as CRYOTE*

Refueling spacecraft on-orbit will be a "Game Changing" technology advancement that will open the door for long term space missions to Near Earth Object's (NEO's) and interplanetary travel.

004-PS Printing The Space Future

Adapting Additive Manufacturing Technology for Zero-Gravity

STATUS QUO

Additive Manufacturing in Zero-G

- Limited zero-gravity testing and physical analysis of 3D printing in zero-g on micro/macro scale
- No testing of building extended structures
- Experimental box is flight ready

NEW INSIGHTS

***Technology Focus Area:* Additive Manufacturing (AM)**

***Specific Benefits of Technology:* Enables In-Situ Manufacturing**

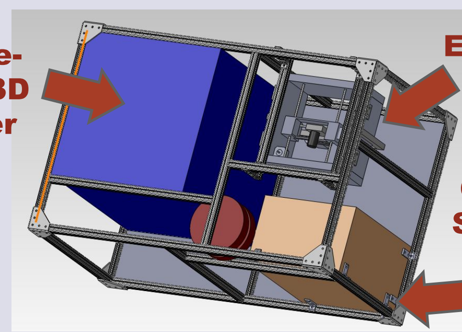
All current space missions depend on Earth. AM will enable in-space manufacturing of parts, spacecraft and large extended structures. Rather than transporting the final part from Earth, only printers and feedstock need to withstand launch stresses.

MAIN ACHIEVEMENT:

This experiment will test the underlining physics of additive manufacturing (AM) in zero-g. Parts will be built in zero-g. Post-flight stress tests and micro/macro analysis will then be compared to parts built on Earth. Using a newly conceptualized Extended Structure Additive Manufacturing Machine (ESAMM), this experiment will also test the concept of building extended structures in zero-gravity. The current ESAMM prototype builds structures several feet long, while a future scaled up model could build in-space structures kilometers in length.

HOW IT WORKS:

AM "prints" parts by adding material layer by layer, causing an efficient use of material. Two OTS AM machines will build cross sections of functional parts. The ESAMM uses worms gears to provide travel in the third direction allowing for a theoretical unlimited amount of layers to be built. The worm gears ride along teeth built into the structure by the AM process.



QUANTITATIVE IMPACT

Flight Experiment Requirements

- ESAMM builds "core sample", a part printed continuously during flight.
- Two OTS FDM printers will fly to test fundamental physics of AM and compare results with ESAMM

Experiment Specifications

- Dimensions: 44in x 22in x 24in

END-OF-PHASE GOAL

Analyze functionality and physics of AM in zero-g environment

- Demonstrate key in-space manufacturing technology
- Flight qualify 3 total AM machines
- Post flight non-destructive and destructive testing of machined parts from flight

Additive manufacturing (often called 3D printing) is an efficient, fast and increasingly automated manufacturing method that will enable the development of in-space infrastructure.

005-P Development and Validation of Design Tools for Advanced, Two-Phase, Space Heat Exchangers

STATUS QUO

- Single phase heat exchangers are currently used for cooling on ISS and other space platforms.
- Two-phase heat exchangers can be more compact, more efficient , and lower weight
- Questions regarding the effect of gravity on two-phase heat exchanger performance prevent their use.
- Current methods of measuring heat transfer during flow boiling are limited to area averaged heat transfer and temperature.

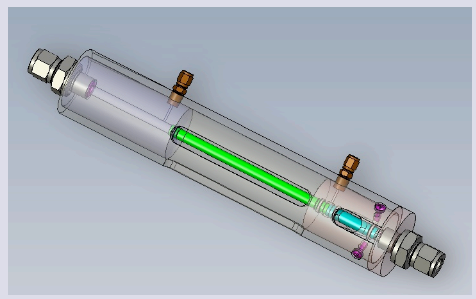
NEW INSIGHTS

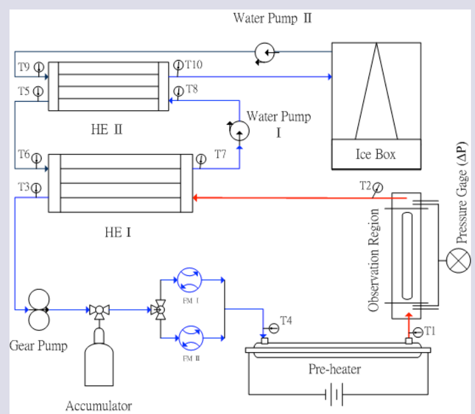
Technology Focus Area: Fluid Physics

A silicon tube 6 mm ID and 1 mm wall thickness is used in con-junction with an IR camera to measure temperature distributions on the wetted wall and to visualize the flow. Half the inner circum-ference is coated with a black opaque paint and the other half is left clear. Mirrors are used to obtain temperature and flow visualization simultaneously.

TEST APPARATUS OVERVIEW:

A closed flow loop has been constructed whereby flow boiling measurements can be made in low-g environments. The experiment is contained within a single test rack (100 cm wide x 750 cm high x 650 cm deep) bolted to the floor of the aircraft. The mass of the apparatus is about 118 kg.





QUANTITATIVE IMPACT

Requested Zero-G conditions

- Up to 30 1.8 g to zero-g parabolas per day
- 4 days of flying

Test Parameters to be varied

- Heater power
- Inlet liquid subcooling
- Inlet mass flow rate
- Heater power

No. of Personnel:

- 3 test personnel per flight

END-OF-PHASE GOAL

Project Impact:

- Results of the tests will allow current models of flow boiling to be tested using local data.
- The data will help develop criterion that will allow the effects of gravity on boiling to be quantified
- The appropriate velocity above which gravity effects can be neglected will be determined

The current experiment allows the local temperatures and heat transfer to be measured with unprecedented spatial and temporal resolution, allowing flow boiling models to be verified.

006-P Electric Field Effects on Pool Boiling Heat Transfer in Low-G Environments

STATUS QUO

- Single phase heat exchangers are currently used for cooling on ISS and other space platforms.
- Pool boiling can provide much higher heat transfer than single phase in low-g, but the amount of heat that can be transported is limited by the lack of buoyancy
- It is known that electric fields can be used to partially replace gravity as a body force, thereby allowing high heat transfer, but the effects are difficult to quantify at present.

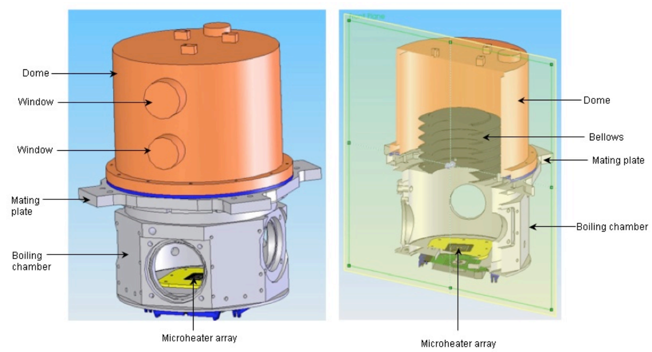
NEW INSIGHTS

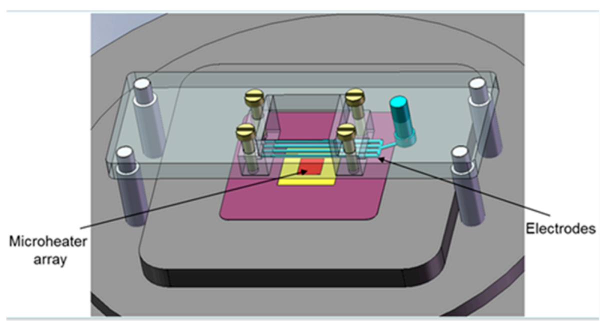
Technology Focus Area: Fluid Physics

A microheater array with 96 independently controllable heaters is used to measure the local heat transfer. An electrode array placed above these heaters will provide a non-uniform electric field that will remove bubbles that are formed on the heater surface. By comparing the heat transfer level with and without electric fields, we can quantify the effective gravity level provided by the electric field.

TEST APPARATUS OVERVIEW:

Two racks are used. The first rack contains the microheater array and the associated control electronics. A second rack contains displays, power supplies, and video recorders. The electrodes are powered by a high-voltage supply up to 20 kV (extremely small currents).





QUANTITATIVE IMPACT

Requested Zero-G conditions

- Up to 30 1.8 g to zero-g parabolas per day
- 4 days of flying

Test Parameters to be varied

- Liquid and heater temperatures
- Electric field intensity

No. of Personnel:

- 3 test personnel per flight

Additional Requirements:
1 air bottle per flight.

END-OF-PHASE GOAL

Project Impact:

- The tests will allow the effective body force provided by an electric field to be quantified under a range of test conditions.
- The data generated will provide experimental results with which to verify models of electric field effects on pool boiling heat transfer, and possibly lead to more compact, higher efficiency space heat exchangers.

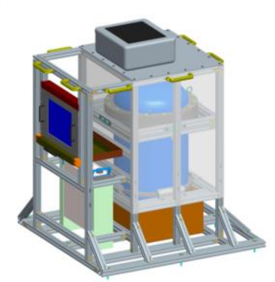
The experiment will quantify the effect of electric fields on heat transfer during pool boiling heat transfer, possibly leading to more compact and efficient space heat exchangers.

Low-g Testing of the Radio Frequency Mass Gauge (RFMG)

PI: Dr. Greg Zimmerli, NASA GRC

Flight Opportunities Program

STATUS QUO



- Propellant quantity gauging in low-gravity typically requires settling burns and the use of level sensors.
- The Radio Frequency Mass Gauge (RFMG) is capable of gauging in zero-g.
- RFMG rig is ready for flight.

NEW INSIGHTS

Technology Focus Area: **Low-g cryogenic propellant quantity sensor**

Specific Benefits of Technology**: Enables fast low-g gauging**

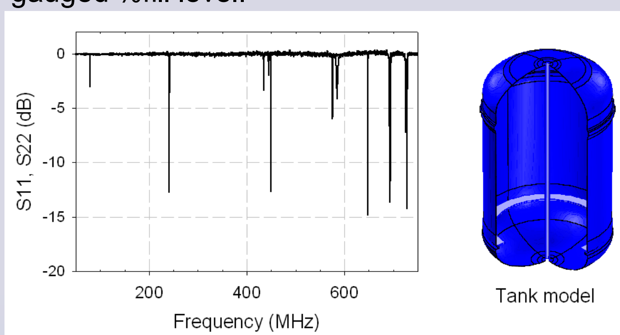
Tests on the low-g aircraft will provide critical test data to measure the accuracy of the gauge in low-g and in the presence of fluid sloshing. A different fluid fill level will be tested each flight day.

MAIN ACHIEVEMENT:

Low-g testing of the RFMG in 2010 showed that the gauge works well when the data is filtered and averaged to mitigate the effects of sloshing. Tests in 2011 will incorporate a slosh baffle and mock "spray bar" hardware elements inside the tank to increase the fidelity of the tests. A digital RC filter will also be applied to the real-time gauge output to smooth the effects of sloshing.

HOW IT WORKS:

The natural electromagnetic modes of the tank are excited by pinging the tank with an RF chirp signal via two small antennas mounted inside the tank. An RF electronics unit measures the RF power spectrum, and software identifies the peaks or mode frequencies. These frequencies are compared to a large database of RF simulations, and a best match occurs at some %fill level which is then reported back as the gauged %fill level.



SPEC'S/ IMPACT

Test Fluid: Fluorinert FC-77

Rig Mass/Dimensions: 465 lbs; 45" x 43" x 53"

RF power: < 1 mW

Frequency: 50 – 750 MHz

Antennas: Z-dipoles (2)

Gauging operations: Once per second, continuously

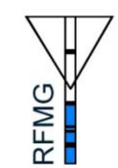
Simulation database: Over 3,000 fluid configuration, fill level combinations

IMPACT: The RFMG provides a way to quickly gauge a tank in low-gravity without having to apply a settling thrust.

END-OF-PHASE GOAL

Demonstrate zero-g gauging at four different fluid fill levels

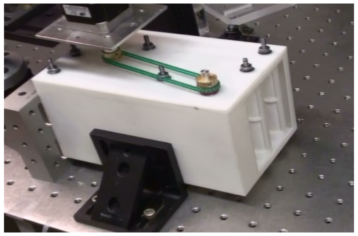
- Advance elements of the technology to TRL-6 through low-g flights
- **Future:** Infuse RFMG technology into commercial launch vehicles and space-based payloads



The Radio Frequency Mass Gauge enables low-gravity gauging of cryogenic propellants.

008-P Indexing Media Filtration System for Long Duration Space Missions

STATUS QUO



Indexing Media Filtration System for Long Duration Space Missions

- Development of advanced particulate filtration systems for long duration missions that feature long service life, regenerability, and require minimal to no crew-tended maintenance
- Replacing filters is typical for 1-g systems but impractical in space.
- Laboratory tested.

NEW INSIGHTS

Technology Focus Area: Life Support Systems
Specific Benefits of Technology: Long life cabin filtration

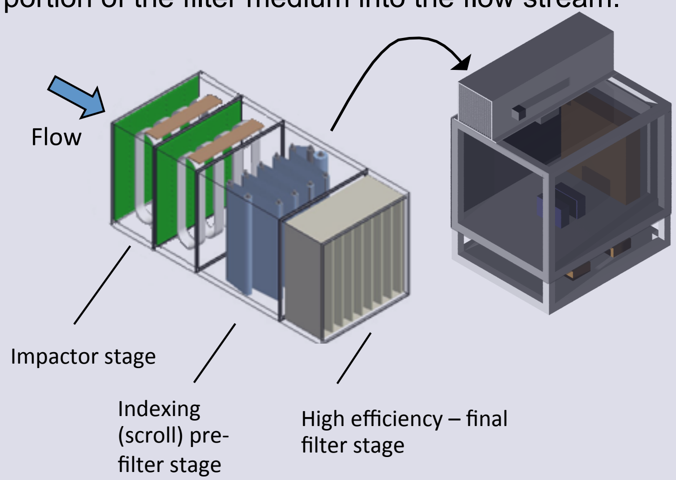
- **Indexing media increases filter area and efficiency.**
- **Indexing reduces filter replacement need.**
- **Indexed media may be regenerated.**

MAIN ACHIEVEMENT:

Develop sustainable regenerable dust mitigation techniques appropriate for space environments.

HOW IT WORKS:

Indexing Media Filtration System uses an advancing web mechanism to advance a fresh portion of the filter medium into the flow stream.



Large particles are separated by impactor plate.

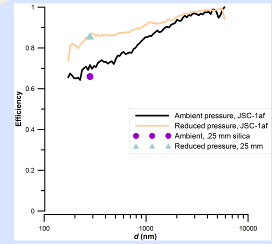
Majority of particles are filtered by indexing media.

Fine particles captured by HEPA filter.

ASSUMPTIONS AND LIMITATIONS:

- Adequate filtration for long duration space missions is unavailable in industry.

QUANTITATIVE IMPACT



Collection efficiency

Flight testing will address the effect of gravity on:

- dust separation capability.
- Collection of large particulates (that tend to settle out in 1-g).
- Dust collection efficiency.
- In-place media indexing..
- Reduced or microgravity operation of the system.

Expected outcome: A prototype filtration system with at least an order of magnitude longer life than state of the art filters, and a particle size filtration range that can be tuned to mission requirements.

END-OF-PHASE GOAL

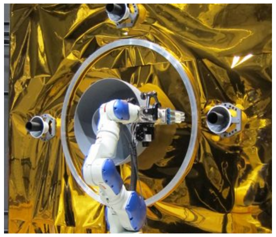
Particulate removal in spacecrafts, habitats, airlocks and pressurized rovers.

- *Enhance the life of filtration systems*
- *Reduce launch requirements*
- *Reduction of system maintenance.*

Filter system components may be renewed, thus extending life and decreasing maintenance

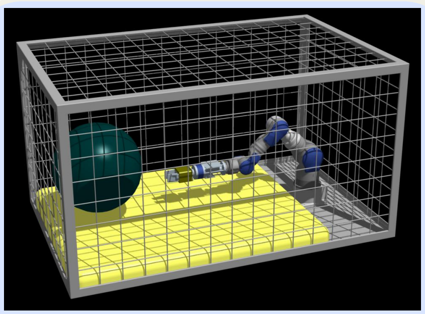
009-P Autonomous Robotic Capture of a Free-Floating Payload in Near-Zero Gravity

STATUS QUO



- Current ground simulations of on-orbit autonomous robotic capture do not adequately model the small-scale 3D contact dynamics between a robot and a satellite
- Some 2D and large-scale/low-bandwidth 3D simulations have been performed

NEW INSIGHTS



NASA's parabolic aircraft provide a unique opportunity to collect data in a zero-g environment in order to advance the fidelity of ground simulations.

MAIN ACHIEVEMENT:

Autonomous robotic capture technologies are being developed to advance the state of robotic servicing technology. A test cage will be flown containing a robotic arm and a free-floating mock satellite that will be autonomously captured.

HOW IT WORKS:

The robot will be fixed to the cage, which will be fixed to the aircraft. During each zero-g period, the mock satellite will be released so that it is free-floating within the cage. The robot will then try to track and grapple the mock satellite using its onboard sensing. A metrology system will independently measure the motion of the arm and mock satellite.

LIMITATIONS:

Each parabola provides only 25 s of zero-g to setup the system and perform capture

EXPECTED PERFORMER:

NASA/Goddard Space Flight Center: Robot control

West Virginia University: Sensing algorithms

U.S. Naval Research Lab: Metrology system

Yaskawa America, Inc: Robot manufacturer

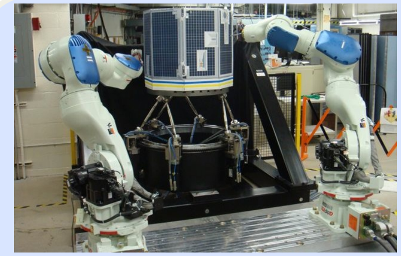
SCHEDULE:

June-July: System development, I&T

July: Zero-g testing

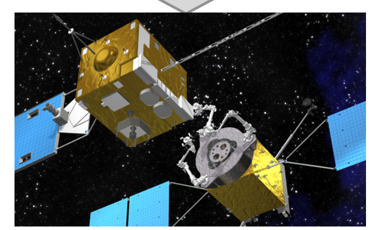
July-Sept: Improvement and validation of ground simulations

QUANTITATIVE IMPACT



- Motion data for the robot and mock satellite will be recorded to replay on ground simulation platforms
- Contact dynamics data will be gathered to validate ground simulations
- Robot sensing data will be captured to further refine capture algorithms

END-OF-PHASE GOAL



Data collected will advance ground simulation fidelity and help NASA address the following RTA Technical Areas: 4.1) Sensing and perception 4.3) Manipulation 4.6) Autonomous rendezvous and docking

These zero-g tests will provide critical data to advance ground simulations which are key to enabling reliable on-orbit robotic satellite servicing

0010-P Validation of a Fine Water Mist Fire Extinguisher

STATUS QUO

- ADA Fine Water Mist (FWM) Portable Fire Extinguishers (PFE)
- Tested on wide range of representative fires including 34% O_2 / 8 psi environment
- Spray fully characterized (droplet size, plume dimensions) in one-g lab

NEW INSIGHTS

(1) Water atomization in microgravity: quality and droplet size distribution (DSD) compared to one-g lab measurements (above). Goal is to confirm that micro-g does not affect droplet formation.

(2) Transport of droplets in microgravity: discharge inside an obstructed enclosure to simulate an ISS rack.

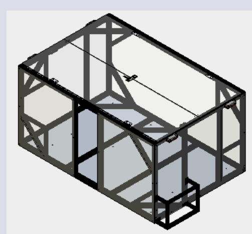
MAIN ACHIEVEMENT: Validate in microgravity a new PFE using FWM and nitrogen for replacement of the current CO_2 PFEs onboard the ISS. CO_2 at fire suppression levels is toxic in occupied spaces. As a result, ISS crew safety will be appreciably improved during fire emergency operations.

HOW IT WORKS: Droplet size distribution (DSD) is determined using a Malvern Spraytec instrument located inside a sealed enclosure in a first experiment. In a second experiment, droplet transport around obstructions is measured via infrared light scattering in a remote region of the same obstructed enclosure. In both cases, the PFE is actuated inside the sealed enclosure.

EXPECTED PERFORMERS: ADA Technologies (Littleton, CO), Colorado School of Mines (Golden, CO) and NASA Glenn Research Center (Cleveland, OH).

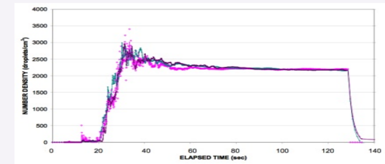
SCHEDULE: July 18-22, 2011.

DELIVERABLES AND DATE: Preliminary flight report (July 29, 2011), Final report (September 23, 2011), Follow up report (July 18, 2012).



ADA sealed enclosure where measurements will be made

QUANTITATIVE IMPACT



Discharge time: 10 s bursts, 6 bursts per PFE

DSD: similar to baseline lab data at 30 cm from instrument beam: D[32]<70 microns, Dv10<20 microns

Spray density at beam: 30-80%

Spray span factor: 1.5 to 3.0

Transport: +10% improvement without gravity (chart above)

END-OF-PHASE GOAL

FWM PFE assures ISS crew safety in firefighting and post fire clean up operations

- *Eliminates the risk of CO_2 poisoning from current PFE*
- *Refillable onboard for longer missions*

Validated, non-CO_2 extinguisher with equivalent performance is critical to improved ISS crew safety

011-P Cryocooler Vibration Analysis for VF-200

STATUS QUO

Sunpower CryoTel™ (CT) cryocooler testing to date.

- Prior µg campaigns, SEED 2010 and FAST 2010, establish commercial technology at TRL 6.
- Thermal testing of CT cryocooler testing in-situ with High Temperature Super Conducting (HTSC) magnet presented need for vibration mitigation at CT-HTSC interface.

Significance of Study:

Vibration characterization

NEW INSIGHTS

Ad Astra's VF-200, VASIMR® (Variable Specific Impulse Magnetoplasma Rocket) Flight - 200 kW, scheduled for testing aboard the ISS in 2014, nozzles plasma propellant via a core of mechanically sensitive HTSC magnets, conduction cooled by CT cryocoolers. Investigation of CT vibration modes will advance TRL of cryocooler technology while simultaneously down selecting mounting interface design.

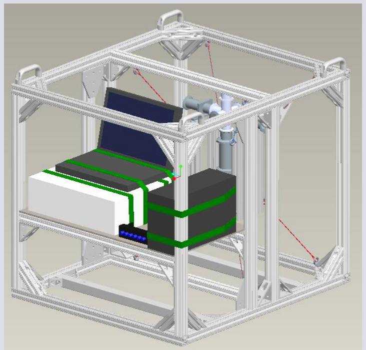
VIBRATION ANALYSIS ACHIEVEMENT

OVERALL OBJECTIVE:

The SunPower CryoTel™ (CT) model cryocooler is a compact Stirling engine device capable of rejecting 10-15 Watts at 40K, ideal for the baseline VF-200. Significant vibrations induced by CT operation pose a hazard to system integrity by degradation of the High Temperature Superconducting (HTSC) magnetic field. The study will advance a solution to mitigate this problem by furthering understanding of CT vibrational characteristics. The experiment is designed to isolate the CT mass system from the experiment frame, reducing the uncertainty associated with vibration transfer.

TEST METHOD:

3-axis accelerometers strategically instrumented throughout experiment provide comprehensive vibration responses at varying cryocooler power levels. Cryocooler operation monitored by current and temperature measurements.



CAD model of experiment rig

QUANTITATIVE IMPACT

Flight Requirements:
40 parabolas/flight x 4 flights

Vibration Measurement:
Accelerometer specifications:
Adjustable sensitivity: +/- 3g or +/11g
Supply voltage: 2.2V-16V
Supply current: 0.5 mA

Experiment interfaces:
Mode of Operations:
Autonomous, LabVIEW controlled.
Power requirements: 115 VAC.

Experiment Specifications:
Mass/Dimensions:
220 lbs. 33in x 33in/ x 37.5in.

END-OF-PHASE GOAL

Measure vibrational characteristics of cryocooler operation.

- Determine natural frequency and intensity of vibrations as a function of test parameters (cryocooler power, g-load, mounting arrangement)
- Offer initial design solution for vibration mitigation.

Sunpower Cryotel™ platform will provide lightweight and compact cryocooling capabilities for the VF-200 test flight aboard the ISS in 2014.